METHANE EMISSIONS FROM SAWDUST/BARK FIRES IN CENTRAL CHILE

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Methane Emissions from Sawdust/Bark Fires in Central Chile

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1. Introduction

The objective of this project is to quantify the emission factors of methane (CH_4) produced during uncontrolled, open-air burning of piled sawdust/bark residue in central Chile. This residue is used by Celulosa Arauco y Constitución S.A. as biomass fuel at the Nueva Aldea and Trupan power plants near Concepcion in Region VIII (Bio-Bio). A field experiment was conducted to quantify methane and other trace gas emissions from the power plants and from burning sawdust/bark residue piles under natural weather conditions in September 2006. Based on the composition of the samples we collected, an average methane emission factor with an associated uncertainty was presented for uncontrolled burning of the piles.

2. Field Site and Conditions

The field experiment was carried out at three different sites. Flue gas samples were collected from two exhaust stacks at the Nueva Aldea and Trupan power plants. The experimental site of pile burns was located at a gravel pit near Canteras in central Chile. Eight piles of biomass fuel used at the power generating plants were arranged in two rows with four piles on each row and approximately 20 m apart between the piles. Each pile was about 2 m high and had a volume of about 30 m^3. The field experiment began on September 7, 2006 and ended on September 14, 2006. The weather conditions during the eight days are summarized in Table 1.

Table 1. Weather conditions during the experiment

Day	Condition	Wind Speed (km/hr)	Average Daytime Temperature (°C)
1 & 2	sunny		14
3	cloudy, light rain	20	10
4	rain	10	8
5	mostly sunny	20	10
6	sunny	20 - 30	8
7	cloudy	10 - 20	8
8	sunny	10 - 20	12

3. Experimental Method

The emissions from the stacks of Nueva Aldea and Trupan power plants were sampled on the day before the open pile burning began. The samples were taken at each site through a port approximately one-third up the stack from a platform on the outside of the stack. A sampling probe of 3 m long was inserted 2.5 m through the port by a plant operator wearing gloves and protective gear, as the exhaust gas in the stack was hot and heated the sampling probe quickly. The sampling system was purged with the flue gas first before a canister sample was collected. Four stack gas samples were collected at each power plant.

For uncontrolled, open burning of sawdust/bark residue, piles of the fuels were covered with plastic sheeting to keep them dry prior to ignition. Once the piles were lit, they were exposed to local weather conditions. Two piles were ignited on the first day. The use of fossil fuels, such as diesel or kerosene, was avoided at the site to prevent contamination of the smoke samples. The ignition method, developed on the site, was to dig a series of small cavities in the pile and ignite the interior of these holes with a propane torch. The propane torch was also used to ignite the outside surface of the pile, but the process was slow. Compressed air was applied to the lighted glowing areas to enhance the combustion process. It took approximately two hours to achieve reasonable ignition of the pile. Then, the pile would burn and stabilize in several hours or until the following day before sampling. Two more piles were ignited the second day, so four piles were burning by the third day. Some piles did not burn as efficiently as the others, and were relit in some spots as the piles ceased burning. By the sixth day all eight piles were burning. The piles diminished in size and collapsed upon themselves as is a common process close to the end of combustion. The size of some of the piles was reduced by two-thirds by the end of the experiment.

The Fire Chemistry group has extensive experience in studying and sampling smoldering emissions of biomass fires in the field. The sampling point of the piles was based on visual observation of smoke production from predominant smoldering combustion, with occasional flaming combustion. The smoldering rate of the piles was variable. The sampling method was based on sampling piles that exhibited natural smoldering behavior, as judged with the experience of the on-site scientists. Wind conditions varied from day to day, and had a significant effect on the rate of combustion.

Smoke samples were collected by placing the sample probe one meter from the pile in the smoke stream, purging the sampling system with smoke, then filling the canister. Samples were collected on average every one to two hours during the first two days of the experiment. More samples per day were collected as more piles were burned at the end of the experiment. A background sample of clean air was collected at the start of each day about 100 m upwind from the burning piles.

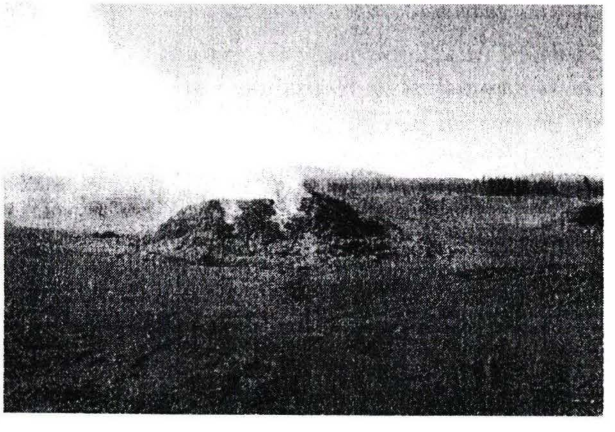

Figure 1. One of the piles was burning on the 5th day of the experiment.

4. Sampling System

The sampling system is a portable unit mounted on a metal frame that can be carried as a backpack to collect a sample either directly from the emission source or from smoke along the perimeter of the pile. It consists of a Rasmussen KNF canister pump with 6 mm (O.D.) stainless steel tubing connected to a T-fitting with a pressure relief valve and a pressure gauge, respectively. The pressure relief valve was used to regulate the pressure of the system and set the final pressure in the canisters. The pressure gauge allowed the operator to monitor the pressure change in the canisters while filling the samples and to check that each canister was evacuated prior to sampling. At the end of each sampling, a purge valve opened to flush out the residual sample in the sampling line. The sampling pump was powered by a 12 volt gel cell rechargeable battery. The flow rate into the canisters was 2 liters/minute and it took approximately 30 seconds to fill each canister.

The inlet of the sampling system was connected to a sample probe (3 m long, 6 mm O.D.) with a flexible 3/8" (O.D.) stainless steel tube and sample canisters. The canisters were 500 ml steel bottles with Nupro model SS-00121 stainless steel ball valves. Canisters were pressurized to 30 psia with either the smoke sample or the clean air sample. Based on our previous tests, the storage time for the light gases measured in this experiment is longer than six months. Thus, within the time frame between sample collection and analysis, it is reasonable to assume that the concentrations of CO_2, CO, CH_4, and non-methane hydrocarbons (NMHC) in the canisters were stable and did not change.

5. Fuel Analysis

Samples of about 100 g sawdust/bark residue were collected prior to ignition of each pile for analysis of fuel moisture content. Samples were immediately weighed in the field with a portable balance. After the samples were transported back to the Fire Sciences Laboratory, they were dried for 24 hours at 100°C and weighed [Allen, 1989].After fuel moisture analysis, a portion of each sample was milled (40 mesh) and sent to the University of Idaho Analytical Services Laboratory for analysis of the carbon content. A CHN (carbon-hydrogen-nitrogen) analyzer was used to perform this analysis.

6. Trace Gas Analysis

Trace gas concentrations in canisters were analyzed at the Fire Sciences Laboratory, using the methodology developed by Hao et al. [1996]. The samples were analyzed for CO_2, CO, CH_4, and C_2 and C_3 alkanes and alkenes with a Hewlett Packard model 5890 Series II gas chromatograph equipped with dual flame ionization detectors (FIDs). The CO_2 and CO analysis utilized a 1 ml sample loop to inject the sample onto a 3.2 mm diameter x 2 m Carbosphere (Alltech) column, with a helium carrier gas (flow rate - 16 ml/minute). After separation of CO_2 and CO in the column, the compounds were passed through a methanizer (375°C) that converted CO_2 and CO to methane, enabling detection by the FID at 350°C. The oven temperature program for this analysis was 30°C for six minutes, 10°C/minute increase to 90°C, and 8 minutes at 90°C. The CH_4 and C_2-C_3 analyses were performed using a 0.25 ml sample loop, a 0.53 mm x 30 m GS-Q (J&W

Scientific) column, with helium carrier gas at a flow rate of 6 ml/min, and FID at 300°C, with a makeup helium gas flow of 14 ml/min. The oven temperature program for this analysis was the same as the program for CO_2 and CO analysis, as both analyses were performed simultaneously.

Chromatogram data was processed and archived by Hewlett Packard ChemStation II software. A set of CO_2, CO, CH_4, and C_2 and C_3 calibration standards at concentrations close to the samples were analyzed each day to construct a standard curve for each compound. Based on the integrated peak areas, the sample concentrations were calculated from the standard curves and written into an Excel spreadsheet. Duplicate samples were analyzed for every sixth analysis. The National Institute of Science and Technology (NIST) primary CO_2 and CO standards were analyzed periodically to verify the response of the detectors.

The emission factor of a compound is defined as the amount (g) of the compound emitted per kg of biomass burned. The emission factor was calculated by the carbon mass balance method [Ward and Radke, 1993]. The computation was based on the emitted, above-ambient concentrations of carbon-containing compounds and the carbon content in the biomass. In this experiment, the carbon-containing compounds of CO_2, CO, CH_4, and C_2 and C_3 gases were analyzed in the sample, and C_2-C_3 gases were summed as the non-methane hydrocarbons. Heavier hydrocarbons were found in trace concentrations in smoke as compared to the major light carbon compounds (e.g., CO_2, CO, CH_4), and accounted for less than 0.01% of the total emitted carbon. Therefore, the omission of measuring the concentrations of high molecular weight hydrocarbons is insignificant in calculating emission factors.

Combustion efficiency is defined as the portion of fuel carbon released as CO_2. The combustion efficiency of complete combustion is 1.0. Modified combustion efficiency (MCE) is defined as the ratio of emitted CO_2 concentrations to the sum of emitted CO_2 and CO concentrations. An MCE value of 1.0 indicates complete combustion. Flaming combustion is indicated by an MCE greater than 0.9 and an MCE of 0.85 or less indicates smoldering combustion.

7. Results and Discussion

The piles were burned under weather conditions for spring- cool, rainy, and moderate winds. The average moisture content of the fuel was 53.9% with a standard deviation of 3.3%. The piles had been covered prior to ignition, so this value may be lower than the fuel moisture content during the rainy season, but probably higher than the moisture content in summer. The carbon content of the fuel was 50.0% ± 0% (n=6), which closely matches the default value of wood carbon content.

A total of 62 emission samples and eight clean air samples were collected and analyzed. The daily average concentrations of the CO_2, CO, and CH_4 in canister samples are shown in Table 2. The complete data set is available in a separate file. Clean air concentrations of 355-423 ppm for CO_2 and 0.1-0.6 ppm for CO were similar to the clean air concentrations

measured in other parts of the world. There were a few elevated values above normal clean air levels, which could be due to a trace of engine exhaust from support vehicles, but these elevated levels were minimal in comparison to the emission concentrations. The background concentrations were subtracted from the pile emission concentrations to obtain net emission concentrations.

The methane concentrations in the flue gases of power plants (0.55 pm) were exceedingly low, even lower than clean air levels (~1.7 ppm to 2.2 ppm). Hence, the combustion process in power generation results in a net loss of methane from the combustion air used. The exhaust gas from the power plant is dominated by CO_2 of 10%-13 % (100,000 ppm to 130,000 ppm) with a trace amount of CO and methane. These measured CO_2 and CO concentrations are similar to those reported by Hao [1986] for CO_2 and CO emissions from power plants in Massachusetts, USA.

The emitted trace gas concentrations during open pile burning are in a similar range to the emitted concentrations in smoldering combustion of other fuel types measured previously at the Fire Sciences Laboratory.

Table 2. Average daily trace gas concentrations (ppm) in samples

Date	Sample	n	CO	CO_2	CH_4	NMHC
06/09/06	Nueva Aldea	4	7.4	132320	0.55	0
	Trupan	4	11.4	104993	1.15	0.23
07/09/06	Background	1	0.6	360	1.99	0.17
	Pile	2	403.0	1942	49.48	14.40
08/09/06	Background	1	0.2	383	1.79	0
	Pile	3	301.7	1434	34.06	7.61
09/09/06	Background	1	0.2	359	2.20	0.05
	Pile	7	231.4	1184	24.56	5.97
10/09/06	Background	1	0.1	360	1.97	0
	Pile	5	150.1	916	14.79	3.35
11/09/06	Background	1	0.1	357	1.83	0
	Pile	9	257.6	1213	24.87	5.36
12/09/06	Background	1	0.2	355	1.79	0
	Pile	14	260.3	1240	24.68	7.58
13/09/06	Background	1	0.1	372	1.82	0
	Pile	13	218.0	1110	22.62	5.28
14/09/06	Background	1	0.4	423	1.97	0
	Pile	9	350.0	1644	32.20	7.47

The average methane emission factor from burning sawdust/bark residue piles collected within a period of eight days is:

13.7 g CH_4 /kg biomass burned, standard deviation of 3.0 g/kg (n=62)

or 740.5 kg CH_4 /TJ biomass burned, standard deviation of 162.2 kg CH_4/TJ

based on the net heat content of fuel to be 18.5 MJ/kg, which was provided by Arauco.

The modified combustion efficiency has been widely used as a quantitative indicator of the combustion process. More efficient combustion has higher MCE values. The results of MCE for each sample are shown in Figure 2. The relatively low, narrow range of MCE (0.7-0.85) indicates that the smoldering combustion process was fairly consistent throughout the experiment, with a few lower values on the last day. There were occasional gusty winds during the last four days, which affected the rate of smoke emissions and fuel consumption. However, the MCE remained relatively constant, only decreasing slightly near the end of the study, indicating the nature of the smoldering combustion was not affected very much in response to normal weather fluctuations.

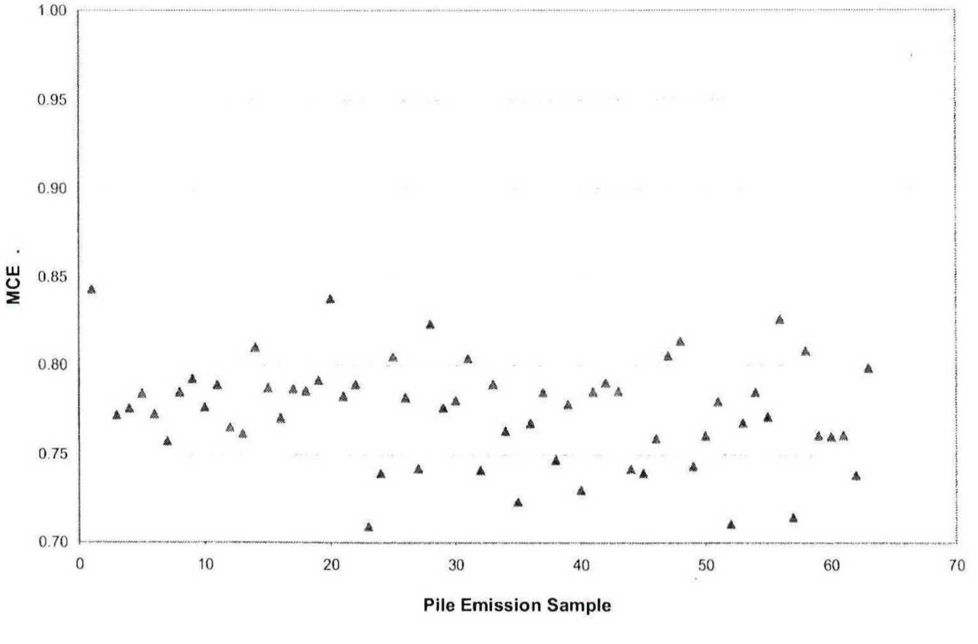

Figure 2. Modified combustion efficiency for each emission sample taken over the eight days of the experiment.

Methane emission factors ranged between 8 g/kg and 20 g/kg most of the time except the last day (Figure 3), when there was more variability. This could be due to the effect of more ash covering the glowing material as the pile burned down. The consistent values of the methane emission factor and MCE indicate that the pile size of this experiment was large enough to offset the daily fluctuations in weather conditions.

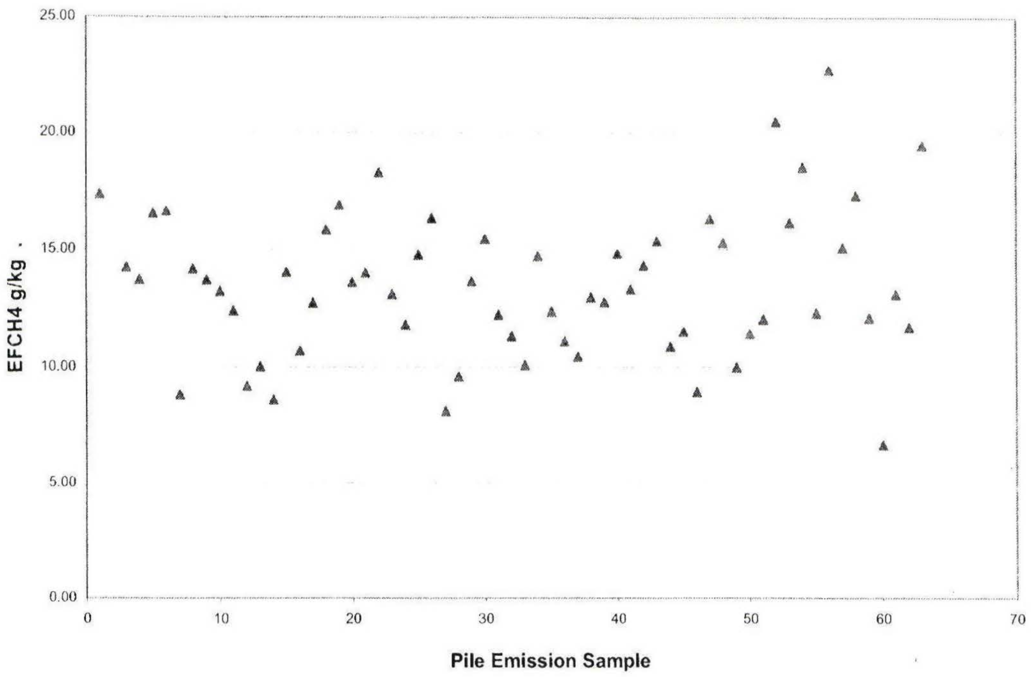

Figure 3. The methane emission factors ($EFCH_4$) for each canister sample collected during the study.

8. Conclusion

The average emission factor of methane was 740.5 kg CH_4/TJ, with a standard deviation of 162.2 kg/TJ, from open, uncontrolled burning of eight sawdust/bark piles in central Chile in September 2006. This value was calculated by averaging the measurements of sixty-two samples collected in eight days. The piles were large enough to adequately represent the combustion process of larger piles. The proposition is based on visual observation of the piles burned and the narrow range of the CH_4 emission factors and modified combustion efficiencies of this experiment. Methane emission factors of open pile burning for this experiment can be higher under similar weather conditions, because flaming combustion was created by digging small tunnels of the piles to speed up the combustion process so as to accommodate the limited experimental time. In large, tightly packed sawdust/bark piles with limited air in the piles and around the combustion zone, smoldering combustion dominates and methane emission factors are usually higher during smoldering combustion than flaming combustion.

9. References

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